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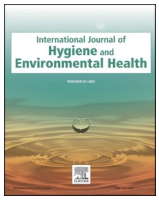

Serum concentrations of PFAS across Australian States and Territories

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ABSTRACT

Background: Australia's long running human biomonitoring (HBM) program has provided information on per and poly-fluoroalkyl substances (PFAS) serum concentrations in the general population since 2002. The program is based on pooling and analysis of surplus, de-identified, pathology specimens predominantly sourced from Australia's north-eastern state Queensland (QLD). To date, potential nationwide spatial differences across Australia have not been assessed.

Aim: The aim of this study was to assess spatial variation of background PFAS serum concentrations across all Australian States and Territories, and to assess if the long running HBM program, representing samples biased towards QLD, can be considered a national reference.

Methods: Surplus pathology serum samples were collected and stratified by States/Territories based on postcode. Pools representing three age groups (5–15, 31–45 and $\geq$ 60 years), stratified by sex were created. Up to two pools for each age/sex strata, consisting of up to 100 individuals, were created for Australian States and major Territories. Samples were analysed for PFAS using high-performance liquid chromatography-mass-spectrometry.

Results and discussion: There was a high degree of consistency in the PFAS serum concentration for a given age/sex among pools from the different States/Territories, particularly for perfluoro carboxylic acids. This suggests that PFAS serum concentrations and associated exposure is relatively consistent across Australia. PFAS concentrations measured in QLD pools were not statistically different from the national average, suggesting that the current Australian HBM program can be considered as a national reference of background PFAS serum concentrations.

1. Introduction

Per- and polyfluoroalkyl substances (PFASs) are a group of manmade compounds that have been used as surfactants in commercial, industrial, and household products since the 1950s. The widespread and high use of PFAS has resulted in ubiquitous presence in the environment worldwide, contributing to human exposure through water, food, air and dust. Environmental persistence and long biological half-lives of some PFAS have led to measurable levels of PFAS in the blood of nearly the entire population (Calafat et al., 2007; Evich et al., 2022). Thus, PFAS are a focus of biomonitoring studies in populations globally.

Differences in background PFAS serum concentrations have been observed in general populations both between as well as within countries (DeLuca et al., 2023; Harada et al., 2010; Jian et al., 2018; Toms et al., 2019). Thus, up to date local data on PFAS concentrations in populations with background exposure is essential to be able to benchmark those who are experiencing elevated exposure, through e.g., contaminated water or chemicals used in the workplace.

In Australia, our long running human biomonitoring (HBM) program is based on pooling and analysis of de-identified surplus pathology specimens that have been collected biannually since 2002 (Harden et al., 2007). Such serum samples have been used to monitor population background PFAS serum concentrations in Australia and have been effective for identifying temporal trends, as well as age and sex trends of

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PFAS (Taucarea et al. 2024; Toms et al., 2014, 2019). Limited spatial trends were assessed using samples collected in 2002-03 comparing broadly defined urban and rural regions, but no substantial difference was observed (Kärrman et al., 2006).

The HBM samples are collected from a pathology laboratory based in southeast Queensland (QLD). Although samples are received nationwide, there is a bias towards samples from QLD, thus contributing to a currently unknown bias on background PFAS serum concentrations used as a reference for the Australian population. Potential nationwide spatial differences across Australia have not been assessed.

In this study, we extended the sampling of the current HBM program to cover samples collected from all Australian States and major Territories. The aim of the study is to i) assess spatial variation of background PFAS serum concentrations across Australia and ii) understand if the long running HBM program, consisting of samples biased towards QLD, is fit for the purpose of representing samples collected on a national level.

2. Methods

2.1. Sample collection and pooling

Ethics approval for this study was granted by The University of Queensland Medical Research Ethics Committee (2013000317) and Queensland University of Technology (1400000581). Samples were obtained in collaboration with Sullivan Nicolaides Pathology from de-identified surplus pathology samples collected in 2020/2021. Samples were obtained nationwide as part of routine pathology testing, following Sullivan Nicolaides Pathology standard operating procedures.

The de-identified samples had limited information including date of birth, sex, date of collection and postcode. Samples from each state/territory; New South Wales (NSW), Victoria (VIC), Queensland (QLD), Northern Territory (NT), Western Australia (WA), South Australia (SA), Australian Capital Territory (ACT) and Tasmania (TAS), were identified based on postcode. Selection of samples was random based on available surplus pathology samples. All postcodes from the selected State/Territories were considered eligible for inclusion and any available samples within the selected age and sex strata was included without any exclusion criteria.

Pools in this study were constructed in accordance with the long running human biomonitoring program described above (i.e., pools consisting of same number of individuals (n = 100), stratified by sex and age group) (Toms et al., 2019). From each State/Territory, samples were collected and pooled according to three age groups (5–15, 31–45 and ≥ 60 years) to capture potential differences across the lifespan, stratified by sex (male, female) (Toms et al., 2019). Each pool comprised of 100 individuals, with some exceptions for the youngest and oldest age group where sample availability was limited, and up to two pools were created for each age and sex group (Table 1). The individual samples were aliquoted using disposable polyethylene pipettes into pools. Equal volumes were taken from each sample within a specified pool. The de-identified data (age, sex and postcode) of each sample included in the pool was recorded.

Table 1
Details of collected pools from each Australian State/Territory; the number of pools from each, the number of individual samples included in the pools and the average age of individuals.

State/Terrotory, Estimated Resident Population[a]	Pooling Strategy						
	Age-group	5–15		31–45		≥60	
	Sex	Female	Male	Female	Male	Female	Male
Australian Capital Territory (ACT)	Pools, individuals	1, n = 50	1, n = 25	2, n = 200	2, n = 200	2, n = 200	2, n = 200
454,499	Average age	10.6	11.0	36.2	37.7	70.6	70.5
New South Wales (NSW)	Pools, individuals	2, n = 200	2, n = 200	2, n = 200	2, n = 200	2, n = 200	2, n = 200
8,072,163	Average age	11.0	10.9	36.5	37.7	72.5	71.1
Northern Territory (NT)	Pools, individuals	1, n = 34	1, n = 20	2, n = 200	2, n = 200	2, n = 175	2, n = 168
232,605	Average age	12.5	11.9	35.9	36.1	67.9	67.8
Queensland (QLD)	Pools, individuals	2, n = 200	2, n = 200	2, n = 200	2, n = 200	2, n = 200	2, n = 200
5,156,138	Average age	11.5	11.0	36.6	37.3	72.0	71.0
South Australia (SA)	Pools, individuals	1, n = 50	1, n = 21	2, n = 200	2, n = 200	2, n = 200	2, n = 200
1,781,516	Average age	12.1	11.3	36.5	37.6	71.8	71.3
Tasmania (TAS)	Pools, individuals	2, n = 200	1, n = 95	2, n = 200	2, n = 200	2, n = 200	2, n = 200
557,571	Average age	11.4	10.8	37.0	36.7	71.5	71.6
Victoria (VIC)	Pools, individuals	2, n = 200	2, n = 200	2, n = 200	2, n = 200	2, n = 200	2, n = 200
6,503,491	Average age	11.1	11.3	37.4	37.8	71.6	71.3
Western Australia (WA)	Pools, individuals	2, n = 125	1, n = 88	2, n = 200	2, n = 200	2, n = 200	2, n = 195
2,660,026	Average age	11.2	11.2	37.1	37.0	69.4	70.1
Sum of pools	Pools, individuals	13, n = 1059	11, n = 849	16, n = 1600	16, n = 1600	16, n = 1575	16, n = 1563
	Average age	11.4	11.1	36.6	37.2	70.9	70.6

[a] Resident Population Australian census conducted in 2021(ABS, 2021b).

2.2. Chemical analysis

Samples were extracted and analysed for 47 PFAS according to previously established analytical protocols using a high-performance liquid chromatograph (HPLC, Nexera, Shimadzu Corp., Kyoto, Japan), coupled to a tandem mass-spectrometer (SCIEX Triple Quad 6500+, Concord, Ontario, Canada) (Nilsson et al., 2021) (List of all PFAS and acronyms are presented in Table S1). Isotope dilution was used for quantification and all PFAS were quantified as linear isomers, PFOS was additionally quantified as the total concentration of both linear and branched isomers. Method detection limits (MDLs) were set as 3.14 times the standard deviation of seven spiked blank samples (RO-water), according to US EPA guidelines (40 CFR 136), and ranged from 0.04 to 1.82 ng/mL (Table S1).

The serum separating tubes used by Sullivan Nicolaides Pathology have been tested for PFAS by adding RO-water and extracting the RO-water after various lengths of storing. No PFAS contamination was detected. We could not control for any potential contamination from previous pathology testing on the serum samples at the pathology laboratory. Further quality control/quality assurance (QC/QA) included the extraction and analysis of procedural blanks (Acetonitrile, MilliQ and calf serum), inter and intra batch duplicates and replicates and standard reference materials (SRM, NIST, 1957) alongside each batch of samples to assess contamination, precision and accuracy. In-house reference samples, spiked pre and post extraction, were used to assess matrix effect and native recovery. Further, the laboratory takes part in an independent quality assurance program (Arctic Monitoring and Assessment Program Ring Test for Persistent Organic Pollutants in Human Serum operated by the Institut national de santé publique du Québec) and has passed assessments during this study's timeframe. QC/QA outcomes are presented in the Supplementary Material (Table S2).

2.3. Statistical analysis

The concentration of PFAS in each pool represents the arithmetic mean concentration of all individuals' serum forming that pool. Thus, when presenting and comparing central tendencies in this manuscript, the arithmetic mean is used. PFAS detected in >80% of samples were used for further assessments of age and sex trends, as well as State/Territory comparisons. Measurements below MDL were substituted as MDL/$\sqrt{2}$ for distribution calculations and statistical assessments. Statistical analysis was performed in GraphPad Prism 10 or IBM SPSS (Version 29). PFAS serum concentrations were ln-transformed prior to statistical testing to improve normality. Appropriate assumptions for each statistical test were assessed, including linearity (visual), normality (Shapiro-Wilk) and variance (Levene's test).

Age trends were assessed using multiple linear regression adjusting for sex. Sex trends were assessed within each age group separately, using point-biserial correlation (Pearsons correlation).

For comparisons, the national average PFAS serum concentration was calculated for each age group and sex. The population varies across States/Territories (Table 1). As an equal pooling protocol was kept for each State/Territory (i.e. two pools of n = 100 for each age group and sex) the national average was set as the population weighted average among all pools collected from each State/Territory to avoid uneven representation. State/Territory specific resident population data for each age group/sex was obtained from the Australian census conducted in 2021 (ABS, 2021b) and used to calculate the weighted average.

General relationships between State/Territories PFAS profile were also assessed graphically using Principal Component Analysis (PCA). In the PCA, PFAS concentrations were normalized to unit variance centred on zero.

To assess spatial differences in PFAS serum concentration between States/Territories, an ANOVA was used. Each PFAS (ln-transformed) was assessed separately. The model was adjusted for age (average age) and sex. ANOVA was followed by the Holm-Šídák test to compare each State/Territory against each other. To assess if the ongoing Australian HBM program, where sample collection is biased towards QLD can be considered to represent samples collected on a national level, we used QLD pools as a proxy for the Australian HBM program. As a proxy for nation wide PFAS levels, we calculated the weighted average using all other States/Territories (i.e. weighted average of pools from ACT, NSW, NT, SA, TAS, VIC & WA). QLD pools were not included in this calculation to not violate the criteria of independence between groups for statistical comparison. QLD pools were compared to the overall weighted average of other states using an ANOVA, adjusted for age and sex.

3. Results and discussion

3.1. PFAS detection frequency and serum concentrations

Of the 47 PFAS analysed, 13 PFAS were detected in at least one pool, including PFBA, PFOA, PFNA, PFDA, PFUnDA, PFDoDA, PFHxDA, PFHxS, PFHpS, PFOS, 6:2 FTS, 5:3 FTCA and 9Cl-53B. Acronym details, detection frequency and strata specific concentrations are presented in the Supplementary Material. PFOS, PFHxS, PFOA and PFBA were detected in all pools, and PFNA, was detected in 99% of the pools. The concentration of these PFAS ranged from 1.4 to 16 ng/mL (PFOS), 0.49–3.2 ng/mL (PFHxS), 0.79–2.8 ng/mL (PFOA), 0.06–0.19 ng/mL (PFBA) and <0.11–0.87 ng/mL (PFNA). PFOA, PFNA, PFHxS and PFOS were moderately to strongly correlated with each other (Pearsons r 0.55–0.83), while PFBA showed weak to moderate correlation with other PFAS (Pearsons r < 0.59) (Table S4, Supplementary Material).

Other frequently detected PFAS included PFDA (73% of all pools) and PFHpS (43% of all pools), in concentrations ranging from <0.09–1.34 ng/mL (PFDA) and <0.06–0.29 ng/mL (PFHpS). 9Cl-F53B (18%, <0.09–1.0 ng/mL) and 5:3 FTCA (15%, <0.05–1.82 ng/mL) were less frequently detected (Table S3, Supplementary Material). F53B and 5:3 FTCA may be potential emerging PFAS in Australia and have recently been reported in other general populations, including from pooled serum samples from Papua New Guinea, as well as individual samples in China (Duan et al., 2020; Nguyen et al., 2023). 5:3 FTCA has also been detected in occupationally exposed ski waxers (Duan et al., 2020). In addition to F53B and 5:3 FTCA, other less frequently detected PFAS include PFUnDA, PFDoDA, PFHxDA and 6:2 FTS which were detected in less than 10% of the pools, in concentrations <0.50 ng/mL.

3.2. Age and sex trends

PFAS with an overall detection frequency >80% (i.e. PFBA, PFOA, PFNA, PFHxS and PFOS), were further assessed for age and sex trends (Tables S5–6, Supplementary Material). A positive association between PFAS and age was apparent for all these PFAS. This age trend has frequently been reported in general populations worldwide, including previously in the Australian HBM (Fu et al., 2014; Jian et al., 2018; Toms et al., 2019), and has been suggested to be a result of longer time of exposure and accumulation of PFAS, as well as potentially lower renal function and elimination (Gekle, 2017). Sex was not associated with PFAS serum concentration for any PFAS in the youngest age group (5–15 years). In the age group 31–45 years, PFOA, PFHxS and PFOS (both linear and total isomer PFOS concentration) were significantly lower in females compared to males. In the age group ≥60 years, females had lower PFHxS concentrations, but higher PFNA concentrations compared to males. Other PFAS were not significantly associated with sex. Additional elimination of PFAS through menstruation is considered a main factor explaining the lower PFAS serum concentrations in females compared to males (Thompson et al., 2010; Wong et al., 2014), explaining why the lower PFOA, PFHxS and PFOS serum concentrations were observed in the female 31–45 years age group, while not always apparent in younger and older age groups. Uncertainties with low concentrations may limit the ability to detect similar trends for PFNA.

3.3. Spatial difference

PFBA, PFOA, PFNA, PFHxS and PFOS were included for the assessment of spatial differences between States/Territories. No clear clustering of States/Territories was observed in the PCA (Fig. S1, Supplementary Material), suggesting no apparent difference in PFAS serum concentration profile between States/Territories. Fig. 1 show the concentrations of PFAS in pools from each State/Territory, and how they relate to the national average.

Perfluorocarboxylic acids (PFCAs), particularly PFOA serum concentrations show a relatively low variation between States/Territories, which is consistent for both sexes and across all age groups (CV of

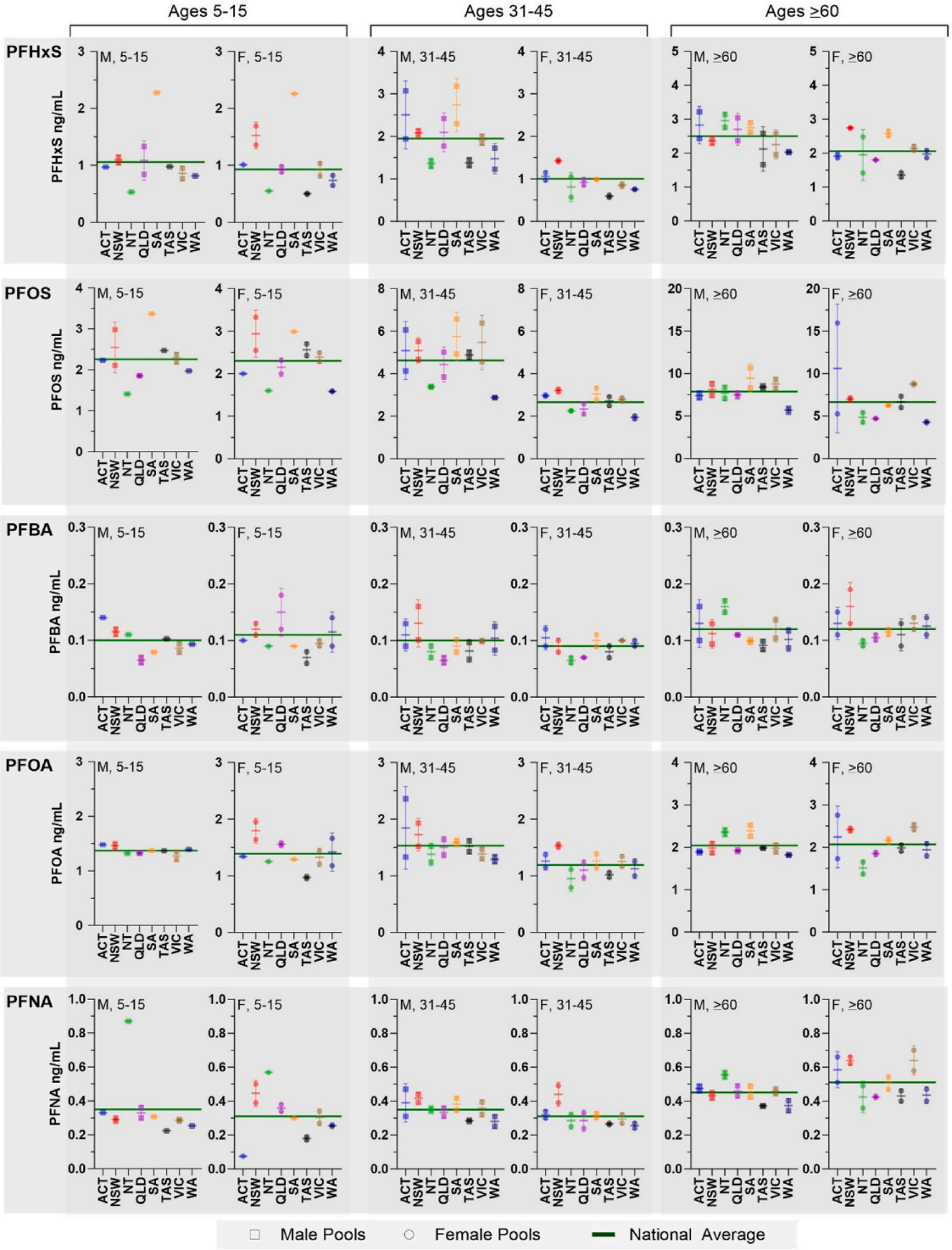

Fig. 1. PFAS serum concentrations of pools collected from Australian States and Territories; Australian Capital Territory (ACT), New South Wales (NSW), Northern Territory (NT), Queensland (QLD), South Australia (SA), Tasmania (TAS), Victoria (VIC), and Western Australia (WA), as well as the weighted average (national average) indicated by the green horizontal line. Apart from one outlier (age group ≥60 years, female, ACT), there was an overall good agreement of PFAS serum concentrations among the two pools within each stratum, with an average coefficient of variation (CV) ranging from 2% to 14%. (For interpretation of the references to colour in this figure legend, the reader is referred to the Web version of this article.)

6–20%). This suggest that the types, number of, and/or degrees of PFOA exposures is relatively similar across Australia.

Another noticeable observation is the significantly higher PFHxS and PFNA concentrations in SA and NT pools respectively, compared to other States/Territories in the youngest age group (5–15 years). However, it should be noted that SA and NT are only represented by one female and one male pool, each consisting of ≤50 individuals. Thus, it is not possible to draw any conclusions from this observation. Continued collection of samples for this age group in SA is currently underway to further investigate this potential exposure trend.

Each State/Territory was compared to each other in an ANOVA, adjusted for both age and sex. One outlier (age group ≥60 years, female, ACT) was not included in this assessment. The outlier pool is likely influenced by one, or a few, individuals with higher levels and thus does not reflect the assumed 'background exposure'.

State/Territory was significantly associated with PFAS serum concentrations for all PFAS that was assessed. The estimated marginal means for each State/Territories derived are shown in Fig. 2,. Pairwise comparisons (Holm-Sidak) between each State/Territory show several significant differences in PFAS serum concentrations. These differences varied for each State/Territory and PFAS compound. More significant differences were observed between State/Territories in perfluoroalkylsulfonate (PFSA) concentrations, compared to PFCA concentrations.

Among PFCAs, only NSW, NT, TAS and WA differed significantly among pools in either PFBA, PFOA and PFNA concentration. Overall, higher PFCA concentrations were observed in NSW pools, and lower in TAS pools.

Each State/Territory had significantly different PFOS serum concentration (both linear and total concentrations) compared to at least one other State/Territory (Fig. 2). Overall, PFOS serum concentrations were lower among pools from NT and WA, and higher among pools from NSW, SA and VIC. While PFOS serum concentrations in TAS pools were neither consistently higher or lower compared to most other States/Territories, the concentrations of PFHxS were consistently lower. Apart from that, PFHxS showed similar trends as PFOS i.e. NSW and SA having higher PFAS serum concentrations among pools, and WA and NT having lower concentrations.

PFOS and PFHxS have been observed to be elevated in firefighters with a history of Aqueous film-forming foam (AFFF) use, as well as individuals from communities affected by AFFF contamination in Australia (Nilsson et al., 2022, 2024; Smurthwaite et al., 2021). Due to the use of de-identified samples, it was not possible to take occupational exposure into consideration. As the postcode of each specimen included in the pools was recorded, these were screened after pooling to assess if

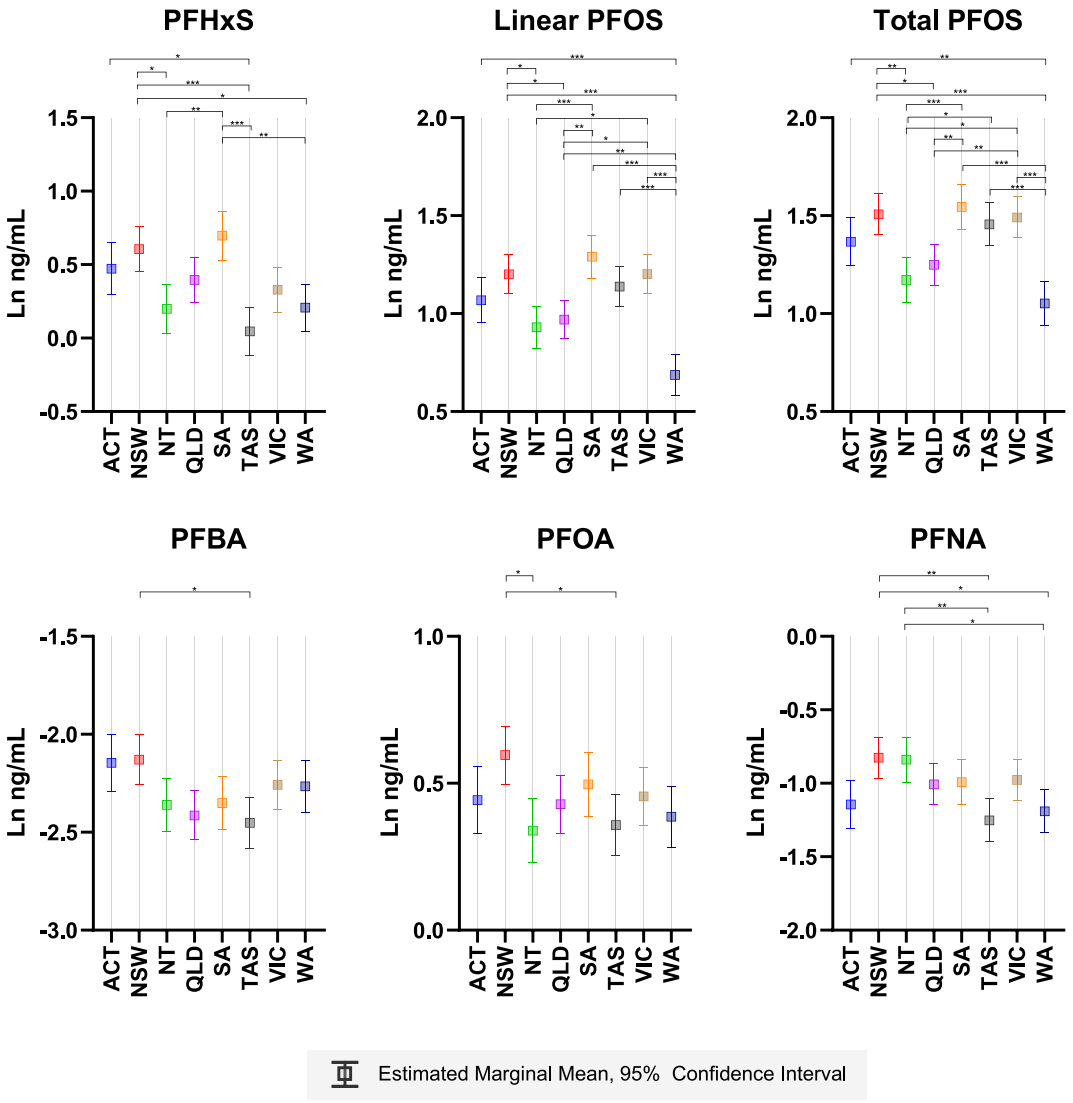

Fig. 2. Estimated marginal means (95% Confidence intervals) of PFAS serum concentration (ln transformed) in pools from each state, as well as the national average (green highlighted area). Pairwise comparison between states was conducted using Holm-Šídák. Covariates are evaluated at the average age of 41.8. *; $p < 0.05$. **$p < 0.01$, ***$p < 0.001$. (For interpretation of the references to colour in this figure legend, the reader is referred to the Web version of this article.)

any specimen were sourced from any known PFAS hotspots. We found that no specimens from postcodes representing known PFAS hotspots wereincluded in the pools. However, it is possible that the donors may have lived/worked in such areas previously, or that there are unknown PFAS hotspots. Thus, some of the differences observed between States/Territories in PFSAs could potentially be attributed to inclusion of one, or a few donors who have experienced occupational exposure or point sources of contamination, and thus not reflect 'background exposure-only' of the State/Territory, but rather differences in occupation and/or areas of contamination.

Nevertheless, although several statistical differences were found in pairwise comparisons between each State/Territory, it is worth highlighting that the differences in mean concentrations were relatively low (i.e. within the typical analytical uncertainties of PFAS analysis (Table S2)).

Differences in diet, consumer product use and other life style factors that have been associated with PFAS exposure may be especially apparent between countries and can help explain differences in PFAS serum concentrations and concentration trends that have been observed internationally (DeLuca et al., 2023; Jian et al., 2018; Nguyen et al., 2023; Nilsson et al., 2023; Park et al., 2019; Toms et al., 2019). However, many of these factors may be less distinct within a country. Previous studies have identified socioeconomics and ethnicity as determinants of PFAS serum concentration within populations in the same country (DeLuca et al., 2023; Park et al., 2019). As the current study relied on pooled de-identified samples, it was not possible to assess such factors in the study population. However, the most recent Australian census (2021), which captures key data on demographics and socioeconomics provides some information about these suggested PFAS determinants across Australia. For example, ACT has the highest median household income, while TAS has the lowest. NSW, ACT, VIC and WA population consist of 29–32% persons that were born in another country, while only 15% of TAS population was born in another country (ABS, 2021a). However, PFAS concentration differences do not reflect this in the current study.

There are also differences in remote areas between the States/Territories. For example, a larger percent of WA and NT consists of remote areas compared to VIC and NSW. Even though no significant spatial trends were observed between urban and rural regions in Australia in samples collected in the early 2000s, updated assessments are needed to understand the contemporary exposure trends associated with remoteness index. Studies in Australia, as well as other countries have observed higher concentrations of selected PFAS in populations residing by coastal areas compared to inland. This could potentially be explained by more frequent seafood consumption in populations living close to the sea (Haug et al., 2010; Orr et al., 2025), and/or exposure through inhalation of PFAS in ocean aerosols or accidental ocean foam if swimming often (Sha et al., 2022). It is possible that there are more apparent spatial differences in PFAS serum concentration not related to States/Territories, but rather geographical indexes. Further research assessing potential geographical specific exposureis needed in Australia.

3.4. Using samples biased towards QLD for Australian HBM

One of the aims of the current study was to investigate if the current Australian HBM data, where sample collection is biased towards QLD can indeed be used as a national reference. We compared the PFAS serum concentrations among QLD pools to the overall weighted average PFAS concentrations estimated from all other States/Territories (i.e. ACT, NSW, NT, SA, TAS, VIC & WA). An ANOVA, adjusted for age and sex, showed no statistical differences for any of the assessed PFAS (Fig. 3).

The consistency between QLD pools and the weighted average of the other states, as well as the lack of distinct PFAS profiles between States/Territories confirmed by the PCA suggests that the current Australian HBM program is fit for the purpose of being a national reference for PFAS exposure in Australia.

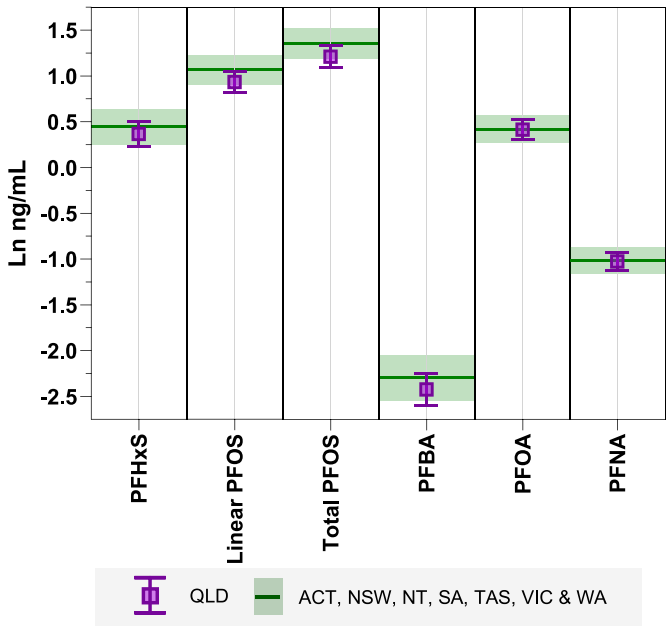

Fig. 3. Estimated marginal means (95% Confidence intervals) of PFAS serum concentration (ln transformed) in pools from Queensland (QLD) (purple) in comparison to the weighted average of all other States/Territories (Australian Capital Territory (ACT), New South Wales (NSW), Northern Territory (NT), South Australia (SA), Tasmania (TAS) Victoria (VIC) & Western Australia (WA)) (green). Covariates are evaluated at the average age of 39.8. (For interpretation of the references to colour in this figure legend, the reader is referred to the Web version of this article.)

3.5. Limitations and further studies

There are limitations associated with the use of pooled de-identified surplus pathology serum samples to assess population exposure which have been discussed in more detail in previous publications (Heffernan et al., 2014; Toms et al., 2019). Some examples include potential contamination as a result of previous pathology testing and sample biases (i.e. potential oversampling of people with adverse health conditions). It is worth noting that the current study did not assess the representativess of pooled pathology samples for establishing general population exposure in Australia. Rather, the PFAS serum concentrations reported in the current study may be used as a reference for population exposure. The study aimed to assess spatial trends, including if samples obtained from QLD are consistent with samples obtained on a national level. Specific limitations associated with these assessments are discussed below.

Due to low sample availability, it was not possible to obtain sufficient number of samples for the lowest age group from all States/Territories, bringing some uncertainty to the comparison across the younger age group. For the same reason it was not possible to assess minor Territories in Australia, such as Jervis Bay Territory, Territory of Christmas Island, Territory of the Cocos (Keeling) Islands and Norfolk Island).

It is also worth to note that the location and/or accessibility to the pathology clinics, relative to population size/population distribution may vary between States/Territories. Thus, the representativeness of pathology samples taken from the population may differ between States/Territories. Additionally, due to the use of de-identified samples, it was not possible to take length of residence or potential health issues into consideration. Furthermore, pooled samples do not provide information on variation in individual sample concentrations in the population, which limits such comparison between States/Territories. The same pooling protocol was conducted for each State/Territory, regardless of the States/Territories population. This is accounted for when estimating the national average by calculating a weighted average.

However, when comparing States/Territories with each other some States/Territories are relatively over (e.g. TAS) or under (e.g. NSW) sampled, thus resulting in under/over estimation of the serum PFAS variance in specific States/Territories. However, due to the large sample sizes obtained from each State/Territory (n ≈ 1000) this is not believed to impact the results significantly.

The study found that PFAS serum concentration estimated from QLD pools, did not appear to be different to the overall average of other States/Territories, which suggest that the current HBM program, which is biased by samples from QLD may currently be fit for the purpose for providing reference values of overall Australian exposure. It is worth to highlight that PFAS serum concentrations have changed and are likely continuing to change over time and thus the relative differences between States/Territories may also be dynamic.

While this study assessed differences between States/Territories, other spatial variations as a function of other indexes may be more important drivers for PFAS exposure. For example, remoteness, ocean proximity or socioeconomics. Further studies are needed to assess such trends in Australia.

4. Conclusion

The current study represents the largest sample size to date (>8000 individuals), for the assessment of PFAS serum concentrations in the Australian general population and allowed a first spatial assessment between States and major Territories of Australia.

Statistically significant differences were observed in PFAS serum concentration measured in pools from Australian States/Territories. The differences varied by PFAS compound, were relatively small, and there was no apparent systematic difference where some States/Territories had consistently higher, or lower PFAS serum concentrations compared to others. PFCAs showed overall consistent concentrations across all States/Territories.

The current long running Australian HBM program, has, and continues to be biased towards QLD due to the availability of pathology serum samples. This study suggests that this geographical sample bias is not introducing a systematic misrepresentation, given that no significant difference was observed between PFAS concentrations measured in QLD pools and the overall average of other States/Territories.

CRediT authorship contribution statement

Sandra Nilsson: Writing – original draft, Visualization, Validation, Methodology, Formal analysis, Data curation, Conceptualization. **Nathaniel Kucharski:** Writing – review & editing, Data curation. **Julia Orr:** Writing – review & editing, Data curation. **Jennifer Bräunig:** Writing – review & editing, Conceptualization. **Kristie Thompson:** Writing – review & editing, Validation, Data curation. **Olivier Jolliet:** Writing – review & editing, Conceptualization. **Daman Langguth:** Writing – review & editing, Data curation. **Carl Kennedy:** Writing – review & editing, Data curation. **Peter Hobson:** Writing – review & editing, Data curation. **Kevin V. Thomas:** Writing – review & editing, Resources, Funding acquisition. **Jochen F. Mueller:** Writing – review & editing, Supervision, Resources, Funding acquisition, Conceptualization. **Leisa-Maree Toms:** Writing – review & editing, Supervision, Resources, Methodology, Investigation, Funding acquisition, Conceptualization.

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Appendix A. Supplementary data

Supplementary data to this article can be found online at https://doi.org/10.1016/j.ijheh.2025.114542.

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